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Ebara Reverse Osmosis Optimization (ROOP) System

by

Amos J. Coleman

Report Date

August 1992

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The Ebara Reverse Osmosis Optimization (ROOP) System was evaluated to determine if it could meet or be adapted to meet the Army's requirement for an automated subsystem capable of providing process control and data acquisition for reverse osmosis water purification units (ROWPUs). The technical operation was satisfactory; however, it was concluded that operationally, the system was too sophisticated for routine field operations with the 600 and 3,000 gph ROWPU. Some benefits may be derived when used with the 150,000 gpd barge which is more analogous to operations in a stationary water purification plant.

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Preface

In March 1974, the Army approved a Required Operational Capability calling for the development of a multipurpose universal water purification unit to provide potable water in the field. Subsequently, a water purification system based on the reverse osmosis (RO) principle and designated the reverse osmosis water purification unit (ROWPU) was developed, procured, and fielded in 600 gallons per hour (gph), 3,000 gph and 150,000 gallons per day (gpd) sizes. A Preplanned Product Improvement program was initiated to conduct testing of new components that could be used to improve the water production capability of the various ROWPU systems. One of the components is an automated controls subsystem to automate and optimize ROWPU operations as a means of reducing manpower requirements and minimizing cost. A survey of the commercial market revealed that Ebara Corporation had patented an automated RO data acquisition and control system that is designed to minimize the overall cost of water production (electric power, chemicals membrane replacement, and manpower) for RO systems while maximizing the computerized process control and data processing. Primarily, the system is designed to control a plant type facility where conditions of the feed water change very little due to elaborate pretreatment systems. However, the Army's ROWPU systems must operate under conditions where the feed water quality can fluctuate and pretreatment is limited. The hardware and software package has been designated the Reverse Osmosis Optimization (ROOP) System. This study will evaluate the ability of the ROOP System to be adapted for military application. This report presents the results of a partial evaluation of the ROOP System.

In FY90, a system was purchased from the Ebara Corporation, International Division, Tokyo, 104 Japan, through a subsidiary, Burton Mechanical Contractors, Inc. (ROOP System Group), Tarazana, CA. The objective of the evaluation was to provide data which could be used in the selection of an automated subsystem for future ROWPUs. This evaluation was authorized under DA Project 1Y665709D650-Exploitation of Foreign Items and conducted by the Belvoir Research, Development and Engineer Center's Logistics Equipment Directorate, Fuel and Water Supply Division, Water Technology R&D Team, at Fort Belvoir, VA.

Section I
INTRODUCTION

TECHNICAL OBJECTIVE

The technical objective of this project was to determine if the Ebara Reverse Osmosis Optimization (ROOP) System could meet or be adapted to meet the Army requirement for an automated subsystem capable of providing process control and data acquisition for improved technology Reverse Osmosis Water Purification Units (ROWPUs).

DESCRIPTION

The ROOP System is a computerized data acquisition and control system designed to control reverse osmosis water purification operations. The major components are:

- Main Computer Board with a 68000 central processing unit (CPU);
- RS-232 serial communication port, two Erasable Programmable Read-Only-Memory (EPROM) chips containing the control program, battery backed Random Access Memory (RAM);
- Light-Emitting-Diode (LED) Display;
- Analog to Digital Board for analog instrument transmitter inputs; and
- Digital to Analog Board for computer output control signals.

The CPU uses current RO plant operating data transmitted in real-time by the instruments and the stored optimization program to calculate optimum operating parameters and output process data to enhance water production. The optimization program and control computer also provide real-time RO data display, graphing, and reporting to a personal computer (PC). In addition, the PC is used to make changes in control variables. The advantages to this type of automation are efficient plant operations and a corresponding savings in manpower and supplies. Stored in the memory are the characteristics of the feed pump, impulse turbine, and valves; the properties of the membrane and feed water; the mechanism of desalination along with the amount and maximum available recovery ratio of product water. When this information is processed by the CPU in accordance with appropriate mathematical models, the system quickly performs the arithmetic operations to provide operational data to the system to sustain optimized operation. Through these actions, the ROOP System can provide savings in energy, chemicals, and labor; increased RO membrane life; automatic data collection and self-diagnostics; and, when used in conjunction with a PC, hard copy reports and real-time graphic displays featuring plant operating data such as recovery ratios and salt rejections.

Section II
EXPLOITATION DATA

Impure water usually contains particulate matter, dissolved ions, organic compounds, and bacteria. Reverse osmosis improves the quality of water by removing a majority of these impurities. A reverse osmosis treatment system consists of pumps, valves, meters, gauges, and, most importantly, a reverse osmosis element whose most important component is the semipermeable RO membrane. In order to produce pure water, a high pressure pump is used to pressurize the impure feed water to a value exceeding its osmotic pressure. Pure water passes through the semipermeable membrane while impurities are left behind to be carried away in the waste stream. The basic parameters for monitoring the RO process are feed water temperature, feed and product water flow rates, inlet pressure, differential pressure between the feed and brine streams, feed and product water contaminant concentration (total dissolved solids (TDS) or conductivity), and percent salt rejection. The customary techniques for monitoring and controlling these parameters are inefficient and cumbersome. Improved operation can be realized when automation techniques are put into practice. An overview of conventional versus automatic operation is discussed below.

CONVENTIONAL CONTROLS

The conventional control scheme for an RO unit consists of manual feed and brine control valves; an on-off level switch in the product storage tank; and an instrument panel for controlling and monitoring temperature, pressures, flow rates, high pressure emergency switches, and various water quality parameters. Data collection is performed manually and analyzed infrequently. The operator must monitor the various conditions and make judgments about when to make adjustments or carry out chemical cleaning procedures. Some drawbacks to this type of system are:

- When the high pressure feed pump is first turned on, the pressure surge in the pressure vessels (which contains the elements with the semipermeable RO membrane) can drive particulate matter into the membrane surface of the element, precipitating fouling. In addition, the surge can cause O-rings to slip out of place allowing for passage of untreated water and a reduction in water quality.

- Manual control of the feed and brine valves requires frequent checking and adjustments to maintain the desired product flow rate and system recovery due to changes in feed water temperature, feed water concentration (TDS), and pressure requirements due to membrane fouling.

- Data is collected manually to determine the membrane condition, and the operator must make calculations and determine when adjustments are needed. Errors usually occur because of differences in operator techniques, computational errors, and infrequent data collection.

AUTOMATION

Major benefits are obtained from automation, especially in areas where feed water temperature or TDS fluctuates. Improved operation can be accomplished while performing real-time diagnosis of membrane conditions by continuously monitoring the RO system parameters, automating the RO feed water pump and brine valve controls. Maximum performance can be achieved by eliminating operator error, analyzing real-time data to determine conditions, calculating optimum control settings, and making adjustments so that water production is optimized. In addition, self-diagnostic checks can be made so that the ROWPU can be automatically shutdown when components fail or exceed safe operating limits. Automation can be implemented by employing a control system, a CPU, and optimization software to monitor data transmitted by the system instrumentation to calculate and set optimum operating conditions.

RO MODEL

The main equation in the RO model is:

$$Q_p = A\,(P-\pi)\,f(t) \qquad \text{Equation 1}$$

where: Q_p = Desired Product Flow Rate
A = Membrane Permeability Coefficient for Water
P = Membrane Surface Pressure - Product Pressure
π = Osmotic Pressure at the Membrane Surface - Osmotic Pressure of Product Water
$f(t)$ = Temperature Coefficient

The other equations, which provide parameters such as percent rejection, salt passage, and flow rate, for control of the RO system are:

$$Q_p = K_s\,(C)\,A\,/\,t \qquad \text{Equation 2}$$

where: Q_p = Desired Product Flow Rate
K_s = Membrane Permeability Coefficient for Salt
C = Salt Differential Across Membrane
A = Membrane Surface Area
t = Membrane Thickness

$$Y = Q_p / Q_f \times 100 \qquad \text{Equation 3}$$

where: Y = Percent Recovery
Q_p = Product Flow Rate
Q_f = Feed Water Flow Rate

$$SP = C_p / C_f \times 100 \qquad \text{Equation 4}$$
$$PR = (C_p - C_f) / C_f \qquad \text{Equation 5}$$

where: SP = Salt Passage
PR = Percent Rejection
C_p = Salt Concentration in Product Stream
C_f = Salt Concentration on Feed Stream

TEST PROCEDURE

The test plan was formulated to evaluate both technical and operational capabilities of the ROOP System. A single element RO test stand was redesigned and modified for the technical evaluation. The ROOP System was installed by the Ebara engineering personnel after which testing and evaluation was initiated by Belvoir personnel. An external microcomputer was integrated with ROOP System during setup. Various operating schemes were devised to control the test stand and to evaluate fail-safe techniques for unattended operation of the RO system. A standard test solution of sea-salt was used as RO source water. The operation of the system was monitored by an operator either visually, by directly reading each instrument, or by observing the RO test stand operating data transmitted by the ROOP System to the computer screen. Two types of experiments were designed: first, to collect data and evaluate the capability of the ROOP System program to monitor and/or compute the various RO system parameters such as differential pressure (ΔP), feed and product water conductivities, and the membrane coefficient which indicate the state of the RO system; and second, to test the ability of the ROOP system to monitor the test stand and sound alarms when unusual conditions were detected.

The ROOP System and test stand are schematically diagrammed in Figures 1 and 2 and photographed in Figures 3 and 4. The test stand components are listed in Table 1. The instruments were connected to the ROOP System by means of 4 - 20 milliampere (mA) outputs.

Table 1. Test Stand Instrument List

PARAMETER	RANGE	INSTRUMENT/ MODEL	MANUFACTURER
Feed Temperature (Analog Input)	0 - 100°C	Temperature RTD Probe, Model RTS-31-U-1000-A-4-2-8-H2-X15 with Temperature Transmitter, Model CT-807A-B-(0 to 100°C)	HY-CAL Engineering
Feed Flow (Analog Input)	0 - 20 gpm	Flow Sensor, Model MK515-PO with Signal Conditioner, Model MK514 (Pulse to 4 - 20 mA)	Signet
Product Flow (Analog Input)	0 - 20 gpm	Flow Sensor, Model MK508 with Signal Conditioner, Model MK514	Signet
Flow Control (Analog Output)		Brine Control Valve Material: 316 Stainless Steel Rating: 1,000 psi, 20 gpm Output: 4 - 20 mA Control Signal	Badger Research
Feed Pressure (Analog Input)	0 - 1,000 psi	Smart Pressure Transmitter, Model STG 17-E1G-00000-MBFIC3	Honeywell
Differential Pressure (Analog Input)	0 - 15 psi	Smart Differential Pressure Transmitter, Model STD 130-E1H-00000-S2, MBF1C3	Honeywell
Feed pH (Analog Input)	1 - 14 pH units	pH Analyzer, Model 7773-50-3-22-2-000 (4 - 20 mA output) with pH Transmitter, Model 7079-11-01-247-120-000	Leeds & Northrop
Product pH (Analog Input)	1 - 14 pH units	pH Analyzer, Model 7773-50-3-22-2-000 (4 - 20 mA output) with pH Transmitter, Model 7079-11-01-247-120-000	Leeds & Northrop
Feed Conductivity (Analog Input)	0 - 100,000 µS/cm 0 - 50,000 ppm	Conductivity/Total Dissolved Solids (TDS) Meter, Model 4905-10-33-009-20-000 with Conductivity Transmitter, Model 7079-17-01-300-120-000	Leeds & Nothrop
Brine (Concentrate) Conductivity (Analog Input)	0 - 100,000 µS/cm 0 - 55,000 ppm	Conductivity/Total Dissolved Solids (TDS) Meter, Model 4905-10-33-009-20-000 with Conductivity Transmitter, Model 7079-17-01-300-120-000	Leeds & Northrop
Product Conductivity (Analog Input)	0 - 2,000 µS/cm 0 - 1,000 ppm	Conductivity/Total Dissolved Solids (TDS) Meter, Model 4905-10-33-009-20-000 with Conductivity Transmitter, Model 7079-17-01-300-120-000	Leeds & Northrop
Panic Button (Digital Input)	Manual Switch Closure	Interrupt or Digital Input to sense switch closure for emergency shutdown	
Chemical Pump (Analog Output)	Pump Controller	0 - 20 mA (0 - 5 VDC) Output for pump speed control	

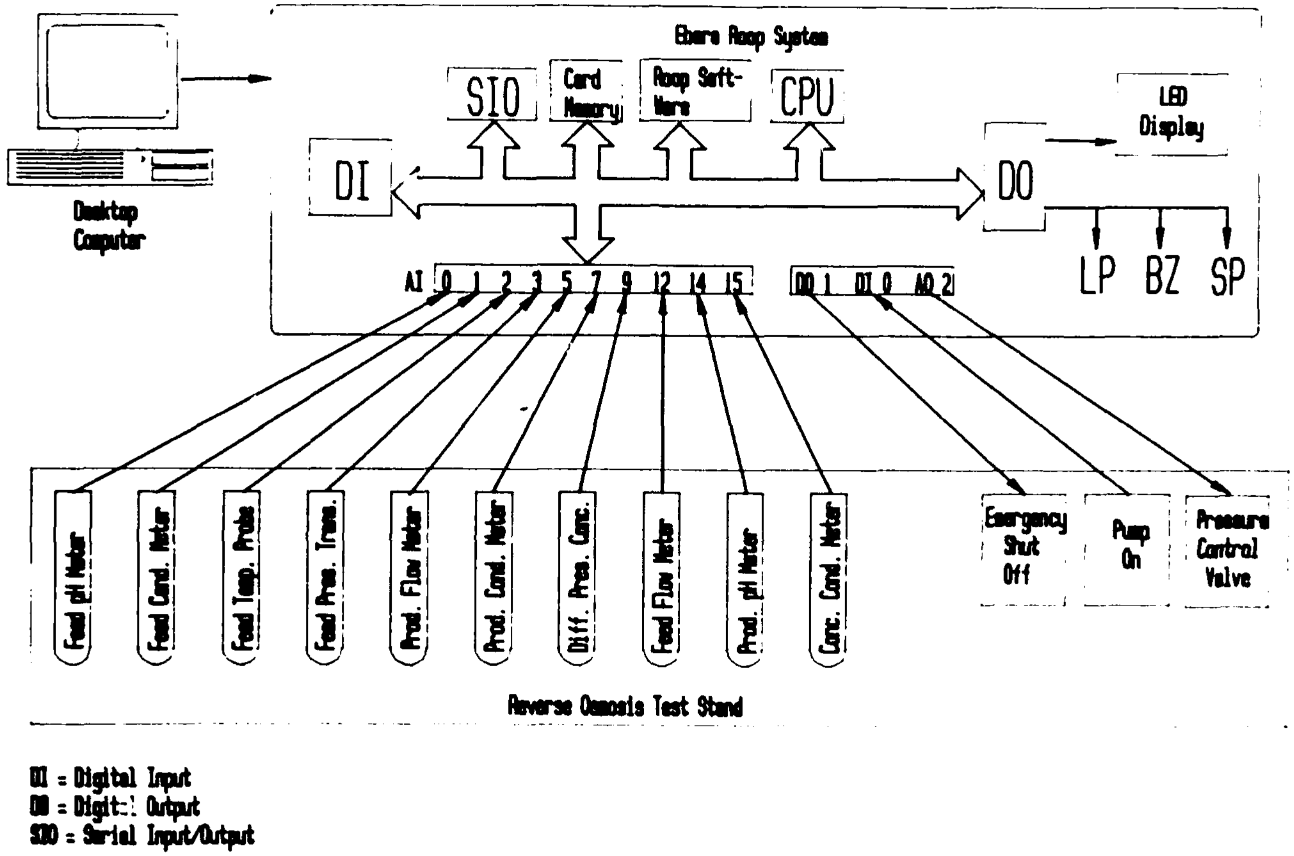

Figure 1. Process and Instrumentation Diagram for the Ebara ROOP System and the Reverse Osmosis Test Stand

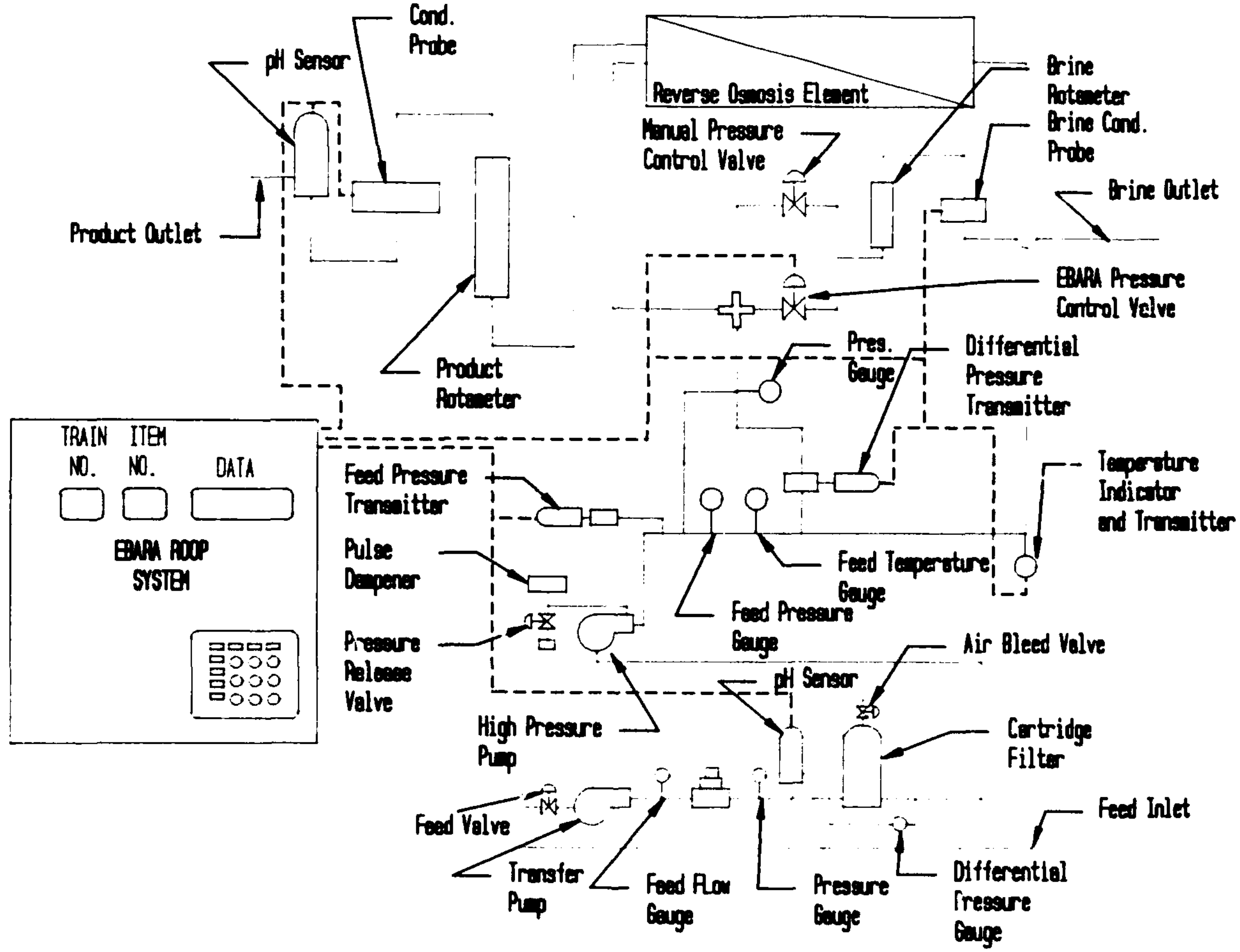

Figure 2. Ebara ROOP Input/Output Interface

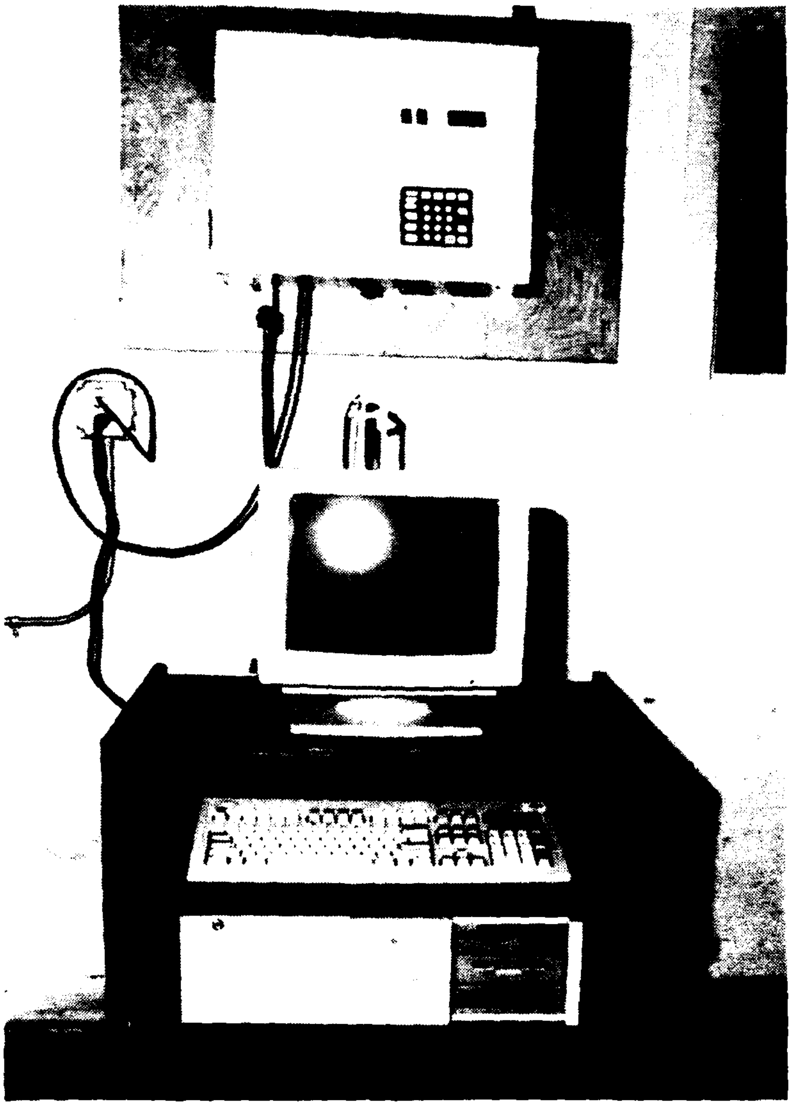

Figure 3. Ebara ROOP System with External Computer

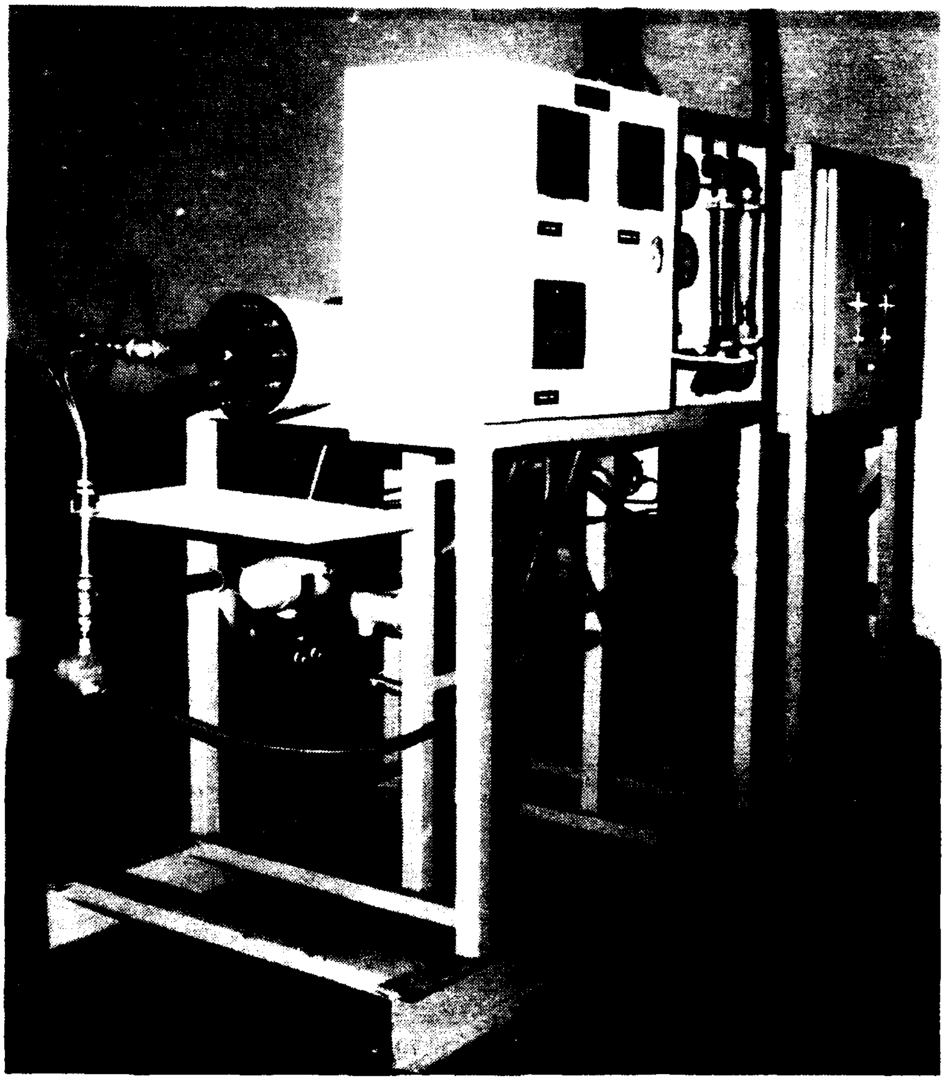

Figure 4. Single Element Reverse Osmosis Test Stand

Section III
RESULTS

The ROOP System performed according to design specifications when operated with the RO test stand. The test stand was first operated in the conventional (manual) mode for several hours in a closed loop with a 35,000 milligram per liter (mg/L) solution of seasalt to establish baseline parameters and to ensure that all components were working properly. During this period, all meters, gauges, and valves were calibrated and set for optimum operation. After these initial tests, the ROOP System was brought on line and allowed to control the RO operation and collect data. The system was fine tuned by adjusting input and output signals using the external microcomputer to input conversion factors, calibration constants, and alarm levels. Over the next several days, the ROOP System operated the test stand by controlling the RO process under steady-state conditions and collecting data every hour. The ROOP System data was compared to the data taken from the individual instruments. A typical data set is shown in Table 2. The data from the ROOP System was in good agreement with both the test stand instrumentation readings and the true values. After determining that the ROOP System could operate properly in the steady-state mode, the system was subjected to several simulated out of range conditions to test performance during an emergency, i.e., the test stand was deliberately perturbed or allowed to exceed safe operating limits in order to determine if, during a malfunction, the ROOP System would promptly and safely shutdown the test stand and sound the alarms. The system successfully passed these fail-safe tests by orderly closing down the test stand when the preset safety conditions were exceeded. Since automatic restart equipment was not available for this test, the test stand was manually restarted. However, the ROOP System did resume control and data collection when the problem was corrected and the test stand restarted.

Table 2. Test Stand Data

Parameter	True Value or Setpoint	Instrument Reading	ROOP System Value*
Feed Water Temperature (°F)	77	77.2	77.2
Feed pH (pH unit)	6.5	6.4	6.4
Feed TDS (mg/L)	35,000	34,960	34,960
Product TDS (mg/L)	np**	250	250
Feed Flow Rate (gpm)	30	18.6	18.3
Product Flow Rate (gpm)	2	1.92	1.94
Feed Pressure (psi)	980	980	978.3
Pressure Differential (psi)	5 (Max)	3.2	3.2

* *ROOP System Values are one time readings taken during steady-state operation. During setup, the instruments are calibrated and their values are assumed to be correct. Subsequently, the ROOP System calibration factors are adjusted to give same values as the individual instruments.*

** *np = The exact value is nonpredictable before performing the experiment.*

Upon completion of the technical evaluation, the project was suspended before testing with a ROWPU because the resources were needed to support Operation Desert Shield/Desert Storm. (The exploitation was later postponed indefinitely when additional funds were unavailable.) Since the evaluation with a ROWPU was not carried out, the following observations are only the opinions of the author.

There are some characteristics of the ROOP System that could restrict the effectiveness of the ROOP System with a fielded ROWPU:

First, a PC must be used to service the system when calibrations, adjustments, and data collections are required; otherwise, the data is read either from the LED readout on the front panel or stored in the system memory for later retrieval. Recording data from the LED readout is analogous to manually collecting data directly from the individual instruments and offers no advantage.

Second, the software is proprietary and supplied on EPROM chips. These chips are reprogrammable but require company personnel who are familiar with the program, an EPROM programmer, and a PC to reprogram them. These components and personnel are unlikely to be available at a field site.

Third, the system is designed to control a plant type facility where RO feed water changes very little due to the use of elaborate pretreatment systems. The Army must use a wide variety of sources for feed water. The quality of feed waters can vary from clear and saline to brackish and muddy with various levels of impurities. The wide range of control needed to operate with the varied quality of feed water that the Army may encounter during extended operations could cause control problems. The ability of the ROWPU in the field to carry out the extensive feed water pretreatment to ensure fail-safe operation of the ROOP System appears to be limited.

Section IV
CONCLUSIONS

It is concluded that the ROOP System is a very good system for automation of plant type RO systems or test stand studies. The system operated as designed; measurements and computations were accurate; and the system was able to monitor and control operations of the RO test stand. However, the ROOP System does not appear as suitable for a field environment especially on small ROWPU systems such as the 600 gph ROWPU. The skill level and accessory equipment needed to maintain the system along with the easy operation of the 600 gph ROWPU does not warrant the addition of another component of this complexity. There may be some value to be achieved by adapting the 3,000 gph ROWPU for automatic operation especially if two will be operating in the same locale for an extended period of time. In this configuration, one ROOP System could manage two 3,000 gph ROWPU systems with a single operator. The most advantageous application for the system appears to be to use it with the 150,000 gallon per day (gpd) ROWPU barges where two usually operate in tandem; a system which is more analogous to a stationary water purification plant.

The performance of the ROOP System was very satisfactory with the RO test stand and it could well be used in a research and development environment where the quality of the feed water is controlled and the skill level of personnel to operate the system is sufficient to make it a valuable tool during testing and qualification of individual RO elements. Presently, plans are being developed to integrate the ROOP System with a new test stand which will be used to support qualification tests for 8-inch RO elements used with the 3,000 gph ROWPU system.

ADDENDUM

It has been learned that, since the termination of this evaluation, the Ebara Corporation is no longer promoting control systems for RO. However, this report may be useful in assessing similar RO automation systems.

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Tobyhanna, PA 18466-5097

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Corpus Christi, TX 78419-6020

1 US Army Foreign Science & Technology Ctr
ATTN: AMXST-IS3
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Charlottesville, VA 22901-5396

OTHER ARMY LIBRARIES

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ATTN: ATAA-SL (Tech Library)
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1 US Army Aviation School Library
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1 US Military Academy
ATTN: Mr. Egon Weiss, Librarian
West Point, NY 10996

1 Commandant
US Army Engineer School
ATTN: Library
Ft. Leonard Wood, MO 65473

1 US Army Humphrey's Engr Spt Activity
ATTN: Library Branch
Ft. Belvoir, VA 22060

1 Engineer Topographic Lab
ATTN: STINFO
Ft. Belvoir, VA 22060

1 Pentagon Library
ATTN: Chief, Reader's Services Branch
The Pentagon, Room 1A518
Washington, DC 20310

1 US Army Corps of Engineers
ATTN: DAEN-ASI-Tech Library
20 Massachusetts Ave, NW
Room 3119
Washington, DC 20314

1 US Army Operational Test & Evaluation Agency
ATTN: Tech Library
5600 Columbia Pike, Room 503
Falls Church, VA 22401

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Code 322
Yorktown, VA 23691

1 Commander
Naval Facilities Engineering Command
ATTN: Library
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Alexandria, VA 22332

1 David W. Taylor Naval Ship RD&E Center
Library Division, Code 5220
Bethesda, MD 20084

1 Naval Air Systems Command
ATTN: Tech Library
Air 00D4
Washington, DC 20361

1 Naval Surface Weapons Center
ATTN: Tech Library
Dahlgren, VA 22448

1 Naval Research Lab
ATTN: Tech Library
Washington, DC 20375

1 Naval Surface Weapons Center
ATTN: Tech Library
Silver Spring, MD 20910

1 Naval Sea Systems Command
Library Documentation Branch
Sea 9661
Washington, DC 20362

1 Naval Ship System Engineering Station
Technical Library
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Bldg 619
Philadelphia, PA 19112

1 Naval Training Equipment Center
ATTN: Technical Library
Orlando, FL 32813

1 HQ, USMC
Marine Corps Technical Library
Code LMA-1
Washington, DC 20314

1 Air Force Systems Command
Technical Information Center
HQ AFSC/MPSLT
Andrews AFB, DC 20334

1 HQ AF Engineering & Services Center
Tech Library FL 7050
Tyndall AFB, FL 32403

1 Defense Systems Management College
ATTN: Library
Bldg 205
Ft. Belvoir, VA 22060

1 Director, Defense Nuclear Agency
ATTN: TITL
Washington, DC 20305

OTHER FEDERAL LIBRARIES

1 Geological Survey Library (GIS)
National Center, Stop 950
12201 Sunrise Valley Drive
Reston, VA 22092

1 National Bureau of Standards (NBS)
E01 Administration Building
Washington, DC 20234

1 Department of Transportation Library
FOB 10A, M494-6
800 Independence Ave, SW
Washington, DC 20591